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☐ *Additional inventors are being named on the _______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHOD AND DEVICE FOR PLANNING A RADIATION THERAPY

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☑ No.
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Respectfully submitted,

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USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Method and Device for Planning a Radiation Therapy

The present invention relates to the field of radiation therapy planning (RTP). In particular, the present invention relates to a method of planning a radiation therapy, to a radiation therapy planning device and to a computer program for a radiation therapy planning device.

Radiation Therapy Planning (RTP) may be carried out using a CT image of a patient acquired prior to the actual radiation treatment. As an input, radiation planning systems require, in particular, contours of the target volume containing, for example, a tumour, and of the healthy (risk) organs which have to be spared during dose delivery. Using these contours, which are delineated by manual or semi-automatic contouring, a dose distribution is calculated for the structures of interest and the optimal parameters of the radiation beams are computed.

However, the dose calculation can become inexact during the treatment process because of shape and position changes of the organs, which may happen due to certain physiological processes, such as bladder filling, increase or decrease of the tumour size, breathing, heartbeat, etc.

It is an object of the present invention to provide for an improved radiation therapy planning.

According to an exemplary embodiment of the present invention as set forth in claim 1, a method of planning a radiation therapy is provided, wherein a dose distribution for a target volume comprising an object of interest is determined on the basis of a first image. Then, at least one of a shape and position variation of an object of interest in the target volume is determined on the basis of the first image and a second image. The dose distribution is then adjusted on the basis of the at least one of shape and position variation of the object of interest. According to an aspect of the present invention, the first and second images were taken at different points in time of a radiation treatment.

In other words, according to this exemplary embodiment of the present invention, an initial dose distribution may be determined on the basis of a first image, which is, for example, taken before the start of the actual radiation treatment. Then, for example, after a plurality of dose deliveries or after a certain time or before a subsequent dose delivery, a second image is taken. Shape and/or position changes of the object of interest, such as the organs, between the first and second images, are determined. Then, the distribution is adjusted on the basis of the shape and/or position variation.

Advantageously, according to this exemplary embodiment of the present invention, a radiation therapy planning may be provided allowing for an improved dose estimation for the target volume. Advantageously, this may allow for an improved tumour control. Furthermore, advantageously, according to this exemplary embodiment of the present invention, the dose calculation may be automatically adjusted taking into account changes to a patient's anatomy.

According to another exemplary embodiment of the present invention as set forth in claim 2, a first surface mesh is applied to the object of interest in the first image and is adapted to the surface of the object of interest which results in a second surface mesh. This second surface mesh is applied to the object of interest in the second image and is adapted to the surface of interest in the second image. This adaptation of the second surface mesh to the object of interest results in a third surface mesh. Then, a difference between the second surface mesh and the third surface mesh is determined.

Advantageously, according to this exemplary embodiment of the present invention, a simple and efficient method is provided for determining the contours of the object of interest in the target volume. Advantageously, by using such a surface mesh adaptation, an automatic organ delineation may be provided.

According to another exemplary embodiment of the present invention as set forth in claim 3, a volumetric model of the object of interest, such as one or more organs, is determined on the basis of the second surface mesh. Then, the volumetric model is deformed on the basis of the difference, i.e., shape and/or position changes of, for example, the organs

between the first image and the second image. The deformation of the volumetric model results in a deformed volumetric model.

According to this exemplary embodiment of the present invention, the shape and/or variation(s) of the object of interest is interpolated into the volumetric model.

According to another exemplary embodiment of the present invention as set forth in claim 4, the difference, i.e., the shape and/or position variation of the object of interest is used as a boundary condition for the deformation of the volumetric model.

According to another exemplary embodiment of the present invention as set forth in claim 5, the at least one of shape and position variation of the object of interest is determined on the basis of the deformed volumetric model.

Advantageously, according to these exemplary embodiments of the present invention, the dose calculation is automatically adjusted taking into account changes of the object of interest between the first and second image, i.e., changes in the patient's anatomy occurring during the time between the first and second images.

According to another exemplary embodiment of the present invention as set forth in claims 6, a model of the biomechanical tissue-properties is taken into account for the deformation of the volumetric model. Advantageously, according to this exemplary embodiment of the present invention, a combination of surface meshes and a biomechanical, volumetric model is used for a very accurate and automatic radiation therapy planning. In particular, the adapted surface meshes are used as boundary condition for the deformation of the biomechanical, volumetric model.

In other words, according to this exemplary embodiment of the present invention, a shape and/or position variation of the object of interest is determined. The object of interest may, for example, contain a plurality of organs, each having different mechanical characteristics. Now, the biomechanical model takes these different mechanical characteristics into account when the shape and/or position variation of the object of interest determined on the

basis of the surface meshes is used to deform the biomechanical, volumetric model accordingly.

Advantageously, this may allow to more accurately take into account non-rigid changes occurring in the patent's anatomy during the radiation treatment.

According to another exemplary embodiment of the present invention as set forth in claim 7, the first and second images are CT images. Alternatively, the procedure is possible with MRI.

According to another exemplary embodiment of the present invention as set forth in claim 8, a radiation therapy planning device is provided comprising a memory for storing the first and second images and a processor performing a dose distribution adjustment on the basis of at least one of a shape and position variation of the object of interest between the first image and the second image.

Advantageously, a radiation therapy planning device may be provided allowing for a fast and accurate radiation therapy planning which may be performed automatically. Advantageously, according to this exemplary embodiment of the present invention, changes of the patient's anatomy are taken into account for determining the dose distribution.

Claims 9 and 10 provide for further exemplary embodiments of the radiation therapy planning device according to the present invention.

According to another exemplary embodiment of the present invention as set forth in claim 11, a computer program is provided for a radiation therapy planning device which allows for an automatic dose distribution determination by a combination of surface meshes applied to the object of interest in at least two subsequent images. By such a combination of a segmentation and a registration, an improved radiation therapy planning may be provided which may allow to reduce a dose applied to healthy (risk) organs. This computer program may be written in any suitable programming language; such as C++ and may be

stored on a computer-readable device, such as a CD-Rom. However, the computer program according to this exemplary embodiment of the present invention may also be presented over a network, such as the world wide web, from which it may be downloaded

It may be seen as the gist of an exemplary embodiment of the present invention that a radiation therapy planning is provided using a combination of a segmentation of a surface of the object of interest in at least two subsequent images and a registration into a volumetric model. In other words, according to an exemplary embodiment of the present invention, surface meshes adapted to surfaces of the object of interest in subsequent images are used as boundary conditions for a biomechanical, volumetric model which takes different mechanical characteristics of, for example, organs within the volume of the object of interest into account.

Advantageously, this may allow for an improved dose estimation in the deformed tissue.

These and other aspects of the present invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

Exemplary embodiments of the present invention will be described in the following with reference to the following drawings:

Figure 1 shows a schematic representation of an exemplary embodiment of a radiation therapy planning device according to the present invention adapted to execute a method according to an exemplary embodiment of the present invention.

Figure 2 shows a flow diagram of an exemplary embodiment of a method of radiation therapy planning which may be implemented as a computer program for a radiation therapy planning device, such as the one depicted in Figure 1.

Figure 1 shows a simplified schematic representation of an exemplary embodiment of a radiation therapy planning device in accordance with the present invention. In Figure 1, there is shown a Central Processing Unit (CPU) or processor 1 allowing to perform the

planning of a radiation therapy with respect to an object of interest in a target volume. The volume of the object of interest may comprise a plurality of other, smaller objects, such as different organs. In other words, the object of interest represents a volume in the target volume or may even correspond to the target volume including a plurality of organs, such as the bladder, the heart, etc. Usually, in cases where a radiation therapy is performed with respect to such target volumes, a tumour is located between or close to those organs. Naturally, the radiation dose should be focused onto the tumour and the healthy (risk) organs adjacent to the tumour should be spared as much as possible.

The processor 1 is connected to a memory 2 for storing images. In particular, in the memory 2, there are stored a first image taken at a first point in time of a radiation process and a second image taken at a subsequent point in time. For example, the first image is taken before the start of the radiation treatment. Then, as mentioned above, an initial dose distribution is determined on the basis of this first image. Then, during the radiation treatment, i.e., for example, after a plurality of radiation treatments or before another immediate radiation treatment, the second image is taken. According to an exemplary embodiment of the present invention, variations in the patent's anatomy, such as shape and/or position changes of the organs in the target volume, are determined from the first image and the second image and the dose distribution is automatically adjusted taking into account these changes in the patient's anatomy.

As may be taken from Figure 1, the processor may, furthermore, be connected by a bus system 3 to a plurality of periphery devices or input/output devices which are not depicted in Figure 1. For example, the image processor 1 may be connected to an MR device, an ultrasonic scanner, to a plotter or a printer or the like via the bus system 3. Preferably, for radiation therapy planning, the processor 1 is connected to a Computed Tomograph (CT) scanner acquiring the first and second images. It has to be noted that according to an aspect of this exemplary embodiment of the present invention, not only two images but a plurality of images may be used.

Furthermore, the processor 1 is connected to a display, such as a computer screen 4 for outputting the initial dose distribution and/or the adjusted dose distribution. Furthermore, a

keyboard 5 may be provided connected to the processor 1, by which a user or operator may interact with the therapy planning device depicted in Figure 1 or may input data necessary or desired for the radiation therapy planning.

Figure 2 shows a flow diagram of an exemplary embodiment of a method of operating the radiation therapy planning device depicted in Figure 1. As already mentioned above, this exemplary embodiment of the method of the present invention may be implemented as a computer program which may be written in any suitable programming language, such as C++ and may be stored on a computer-readable medium, such as a CD-Rom. However, the computer program according to the present invention may also be presented over a network, such as the world wide web, from which it may be downloaded.

The method of this exemplary embodiment of the present invention allows to avoid that the dose distribution determined on the basis of an initial CT image taken before the actual start of the radiation therapy becomes inexact during the treatment because of shape and/or position changes of the organs, which may happen due to certain physiological processes, for example, bladder filling, increase or decrease of the tumour size, breathing, heartbeat, etc. Ideally, according to an aspect of the method according to this exemplary embodiment of the present invention, the dose distribution is individually adjusted for each day of treatment, i.e. the dose calculation is automatically adjusted taking into account changes in the patient's anatomy from one day to the other. For this, new CT images should be taken for each day of treatment.

In Figure 2, two CT images are used for adjusting the dose distribution. The first CT image is referred to as initial CT image 12 and the second image is referred to as new CT image 14. Preferably, the initial CT image 12 is taken before the start of the actual treatment and the new CT image 14 is then taken during the treatment process, for example, right before a radiation treatment.

According to this exemplary embodiment of the present invention, the organ boundaries in the target volume are delineated. The delineation of the organ boundaries in the initial CT image 12 may be performed manually or semi-automatically. Preferably, according to this

exemplary embodiment of the present invention, 3D surface models are used for performing an automated organ boundary delineation such as described in J. Weese et al, "Shape constrained deformable models for 3D medical image segmentation." In Proc. Information Processing in Medical Imaging (IPMI '01), pages 380-387, Los Angeles, CA, USA, June 2001, which is incorporated by reference.

In accordance with the application of 3D surface models, a surface mesh, such as a triangular mesh, is applied to the organs in the initial CT image 12. It should be noted that instead of triangular meshes, it is also possible to use simplex or polygonal meshes or other suitable surface or shape models. Then, this surface mesh is adapted to the surface of the organs in the initial CT image 2 by energy minimization. Such adaptation of a surface model to the actual organ surface is described in further detail in J. Weese et al, "Shape constrained deformable models for 3D medical image segmentation." In Proc. Information Processing in Medical Imaging (IPMI '01), pages 380-387, Los Angeles, CA, USA, June 2001, which is hereby incorporated by reference.

After or parallel to the determination of a surface mesh representing the shape and/or position of the organs in the initial CT image 12, a delineation of the boundaries of these organs is performed in the new CT image 14. Preferably, according to an aspect of this exemplary embodiment of the present invention, the segmentation result of the initial CT image, i.e., the surface mesh adapted to the organ surfaces in the initial CT image 12 is used as a starting mesh in the new CT image 14. Then, this starting mesh is adapted to the organ surfaces of the organs in the new CT image 4 by energy minimization in the same way as described above. After the adaptation of the surface mesh to the organ surfaces in the new CT image 14, two surface meshes are known representing the organ surfaces in the initial CT image 12 and in the new CT image 14. The first mesh representing the organ surfaces in the initial CT image 12 is referred to in Figure 2 as surface1 and the second mesh representing the surfaces of the organs in the new CT image 14 is referred to surface2 in Figure 2. In a subsequent step, a difference between the surface1 and the surface2 is determined. In other words, correspondences between the surface1 and surface2 are determined. For this, the initial CT image 12 and the new CT image 14 or the surface1 and surface2 are brought into a common co-ordinate system. Since surface1 and

surface2 were determined by using the same surface model, point correspondences between surface 1 and surface 2 may be determined easily.

Then, in a next step, a volumetric mesh is generated from the surface 1 in the initial image. According to an aspect of the present invention, this volumetric mesh is now deformed using the point correspondences obtained from the comparison of surface1 and surface2.

According to an exemplary embodiment of the present invention, the deformation of the volumetric mesh is determined by taking into account mechanical properties of the organs, by using one or more biomechanical models. The use of biomechanical models is, for example, described in D. Yan et al, "A method for calculating dose in a deforming organ." Int. J. Radiat. Oncol., Biol., Phys., 44, pages 665-675, 1999, which is hereby incorporated by reference.

An example for a simple and efficient biomechanical model is described in the following: Let V bé a 3D domain occupied by the organ of interest and S be the organ boundary. A boundary value problem describing a linear elastic deformation of the organ can be formulated as:

$$\begin{cases} \int_V \mathbf{A}(\mathbf{u}) = \mathbf{f}(\mathbf{x}) & \text{in } V, \\ \mathbf{u}(\mathbf{x}) = \hat{\mathbf{u}}(\mathbf{x}) & \text{on } S. \end{cases}$$

In the above formula, A(u) denotes the operator of linear elasticity, as, for example, described in P. G. Ciarlet, "Mathematical Elasticity, Volume 1: Three-Dimensional Elasticity, volume 20 of Studies in Mathematics and its Applications." North-Holland, Amsterdam, 1988, which is hereby incorporated by reference. f (x) are the applied forces. u(x) denotes the displacement field, where û(x) are the prescribed displacements on the boundary determined by using the surface meshes. A discretization of the above formula on the volumetric mesh by the finite element method results in a linear system of equations. Prescribed displacements can be included into the system as boundary conditions to constrain the resulting volumetric deformation. According to an aspect of the

present invention, these boundary conditions correspond to the point correspondences between the surface1 and surface2.

Elastic properties of particular tissues can be assigned to individual tetrahedra in the 3D mesh to more exactly simulate the elastic behaviour of an organ (the organs). If the organ deformation is large and cannot be adequately described by the linear model, a non-linear elastic model in the form of incremental deformation may be applied.

As a result, advantageously, displacements of individual nodes inside the organ may be computed. During radiation treatment, dose estimation in the volume of interest can be performed taking into account variations or changes of the patient's anatomy based on these computed displacements. This estimation is then used to predict the dose delivery and helps to correct the initial treatment plan.

As described above, according to the present invention, a combination of a segmentation and a registration is applied to take variations in the patient's anatomy during the radiation treatment into account to adjust the dose distribution and dose delivery estimation. This is achieved by combining a surface matching method, such as the one described in J. Weese et al, "Shape constrained deformable models for 3D medical image segmentation." In Proc. Information Processing in Medical Imaging (IPMI 01), pages 380-387, Los Angeles, CA, USA, June. 2001, which is hereby incorporated by reference, with a biomechanical, volumetric model. In particular, the result of the surface method is used as boundary condition for the biomechanical, volumetric model.

Advantageously, due to the above method, the dose delivery during the treatment process may be monitored. For each point in time, where an image was taken, due to the above method, the precise dose distribution can be determined. In other words, for each relevant point in time of the treatment, and for each point of interest in the target volume (risk organs) the dose delivered can be determined. This may be done by summing the dose during each dose delivery to respective points.

Having described a preferred embodiment of the invention, the following is claimed:

1. Method of planning a radiation therapy, the method comprising the steps of:

determining a dose distribution for a target volume on the basis of a first image;

determining at least one of shape and position variation of an object of interest in the target volume between the first image and a second image; and

adjusting the dose distribution on the basis of the at least one of shape and position variation;

wherein the first and second images where taken at different points in time of a radiation treatment process.

2. The method of claim 1, further comprising the steps of:

applying a first surface mesh to the object of interest in the first image;

performing a first adaptation of the first surface mesh to a surface of the object of interest in the first image resulting in a second surface mesh;

applying the second surface mesh to the object of interest in the second image;

performing a second adaptation of the second surface mesh to the surface of the object of interest in the second image resulting in a third surface mesh;

obtaining a difference between the second surface mesh and the third surface mesh.

3. The method of claim 2,

generating a volumetric model of the object of interest on the basis of the second surface mesh;

deforming the volumetric model on the basis of the difference resulting in a deformed volumetric model.

4. The method of claim 3,

wherein the difference is used as boundary condition for the deformation of the volumetric model.

5. The method of claim 3,

wherein the at least one of shape and position variation of the object of interest is determined on the basis of the deformed volumetric model.

6. The method of claim 3,

wherein a biomechanical model is taken into account for the deformation of the volumetric model.

7. The method of claim 1, wherein the first and second images are computed tomography (CT) images.

8. Radiation therapy planning device, comprising:

a memory for storing a first image and a second image; and

a processor adapted to perform the following operation:

determining a dose distribution for a target volume on the basis of the first image;

determining at least one of shape and position variation of an object of interest in the target volume between the first image and the second image; and

adjusting the dose distribution on the basis of the at least one of shape and position variation;

wherein the first and second images where taken at different points in time of a radiation treatment process.

9. The radiation therapy planning device of claim 8, wherein the processor is further adapted to perform the operation of

applying a first surface mesh to the object of interest in the first image;

performing a first adaptation of the first surface mesh to a surface of the object of interest in the first image resulting in a second surface mesh;

applying the second surface mesh to the object of interest in the second image;

performing a second adaptation of the second surface mesh to the surface of the object of interest in the second image resulting in a third surface mesh;

obtaining a difference between the second surface mesh and the third surface mesh;

generating a volumetric model of the object of interest on the basis of the second surface mesh; and

deforming the volumetric model on the basis of the difference resulting in a deformed volumetric model.

10. The radiation therapy planning device of claim 9,

wherein the difference is used as boundary condition for the deformation of the volumetric model; and

wherein a biomechanical model is taken into account for the deformation of the volumetric model.

11. Computer program for a radiation therapy planning device, wherein a processor of the radiation therapy device performs the following operation when the computer program is executed on the processor:

determining a dose distribution for a target volume on the basis of a first image;

applying a first surface mesh to the object of interest in the first image;

performing a first adaptation of the first surface mesh to a surface of the object of interest in the first image resulting in a second surface mesh;

applying the second surface mesh to the object of interest in the second image;

performing a second adaptation of the second surface mesh to the surface of the object of interest in the second image resulting in a third surface mesh;

obtaining a difference between the second surface mesh and the third surface mesh;

generating a volumetric model of the object of interest on the basis of the second surface mesh;

deforming the volumetric model on the basis of the difference resulting in a deformed volumetric model; and

adjusting the dose distribution on the basis of the deformed volumetric model;

wherein the first and second images where taken at different points in time of a radiation treatment process.

Abstract

During radiation therapy planning, a dose calculation can become inexact during the treatment process because of shape and position changes of the organs. According to the present invention, the dose distribution is adapted on the basis of shape and position variations of the organs of interest determined from a comparison of a first image and a second image which were taken at different points of time during the radiation treatment process. Advantageously, the first image was taken before the start of the actual radiation treatment. Advantageously, this may allow to automatically adjust the dose calculation taking into account the changes in the patient's anatomy.

24494.1

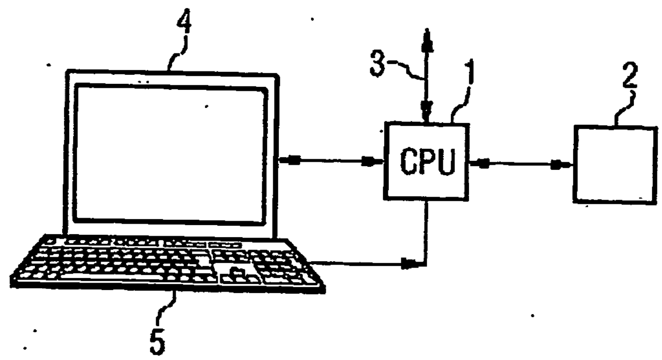
4
3
1
2
CPU
5

FIG 1

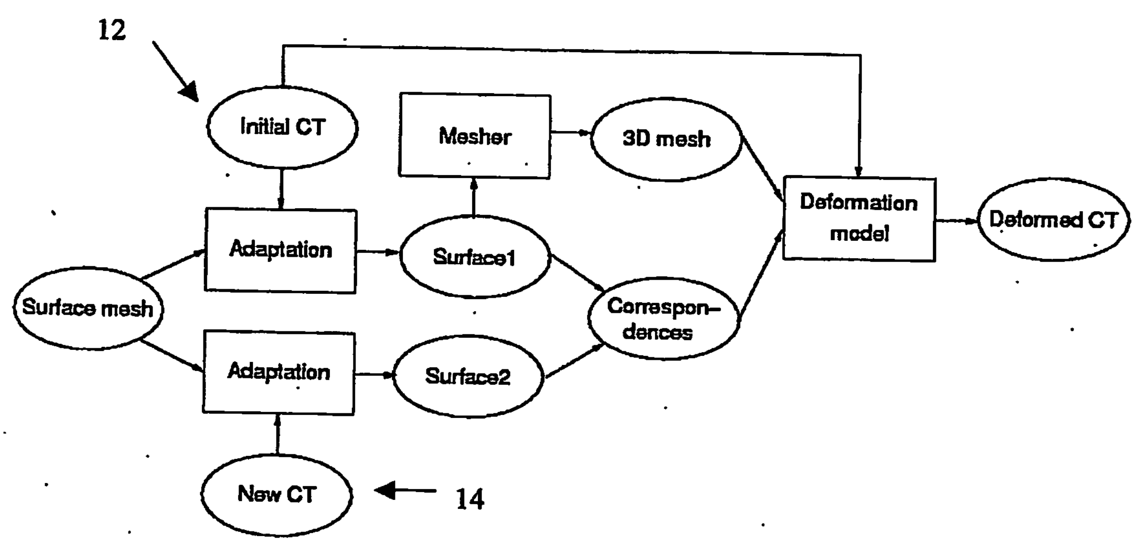
12
Initial CT
Mesher
3D mesh
Deformation model
Deformed CT
Adaptation
Surface1
Surface mesh
Correspon-dences
Adaptation
Surface2
New CT
14

Fig. 2